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CATEGORIZATION AND IDENTIFICATION OF SIMULTANEOUS TARGETS

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ABSTRACT

Several studies have shown that the time to detect whether a single target categorically different from non-targets is present or not, is relatively independent of the number of non-targets in the display. Invariance of performance with display size is taken as evidence in favor of late-selection theories claiming unlimited-capacity, spatially parallel processing of all items in the display. As an extension of previous studies, in the present study two categorically different targets were presented simultaneously among a variable number of non-target. Subjects were shown brief displays of two target letters among either 2, 4 or 6 non-target digits. Subjects responded "same" when the two letters were identical and "different" otherwise. Since the "same-different" response reflects the combined outcome of the simultaneous targets, late-selection theory predicts that the time to match the target letters is independent of the number of non-target digits. Alternatively, early-selection theory predicts a linear increase of reaction time with display size since the presence of more than one target disrupts parallel pre-attentive processing, leading to a serial search through all items in the display. The results provide evidence for the early-selection view since reaction time increased linearly with the number of categorically different non-targets. Netherlands

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Categorisatie en identificatie van simultaan aangeboden targets

J. Theeuwes

SAMENVATTING

In de literatuur is uit eerdere studies naar voren gekomen dat tijd nodig voor de detectie van één target cijfer tussen non-target letters, of één target letter tussen non-target cijfers relatief onafhankelijk is van het aantal non-targets dat aanwezig is in een display. Deze resultaten worden beschouwd als evidentie voor "late-selection" theorieën die een spatieel parallelle verwerking van alle items in het display veronderstellen. Om deze hypothese nader te toetsen werden - in afwijking van eerder onderzoek - in de huidige studie twee target letters tegelijkertijd gepresenteerd met 2, 4, of 6 non-target digits. Proefpersonen reageerden op de aan- of afwezigheid van twee identieke target letters. Omdat de "same-different" respons gebaseerd is op het vergelijken van de simultaan aangeboden targets, voorspelt de "late-selection" theorie dat de tijd nodig voor het geven van de respons onafhankelijk is van het aantal non-targets. Anderzijds voorspelt de "early-selection" theorie dat de reactietijd lineair toeneemt met het aantal non-targets omdat de aanwezigheid van meer dan één target een verstoring zou geven van de parallelle pre-attentieve verwerking. De resultaten geven evidentie voor de "early-selection" theorie. De resultaten van een visueel zoekexperiment met simultaan aangeboden targets gaf steun aan de gedachte dat het niet mogelijk is om parallel meerdere targets tot op een semantisch niveau te identificeren.

1 INTRODUCTION

Studies on visual attention are concerned with human limits in identifying simultaneously presented stimuli. This has led to experiments on visual search in which the number of elements in a display has been varied. In such conditions, a linear effect of display size is usually found implying that the time to detect a target increases as a linear function of the number of non-targets. However, the display size effect is very much reduced when subjects search for a letter among digits, or a digit among letters. This reduction is attributed to the categorical difference between target and non-targets (cf. consistent mapping; see Shiffrin & Schneider, 1977). Alternatively, search for a target letter or digit among non-target items of the same category shows the typical effect of display size suggesting a serial scan through all items of the display (Egeth, Jonides & Wall, 1972; Gleitman & Jonides, 1976, 1978; Jonides & Gleitman, 1972, 1976). For example, Gleitman and Jonides (1976) obtained a RT function of 29.9 ms/item for searching for a within-category target, whereas a relatively flat RT slope of 9.9 ms/item was found for detecting a categorically different target. The category effect is important in theories regarding visual information processing because it has suggested that characters are processed spatially parallel with unlimited capacity (e.g., Duncan, 1980; Hoffman, 1979; Garner, 1973). However, this conclusion is not generally accepted and there remains some controversy about the processing underlying the category effect (e.g., Kahneman & Treisman, 1984).

A common explanation of the category effect is that category information can be used to separate relevant from irrelevant items. In this view, all items in the display are actually identified and categorized in parallel without requiring selective attention. Categorization would always accompany identification (Duncan, 1985), which relates to Taylor's (1978) claim that identification and categorization of digits and letters occur simultaneously and that either type of information is derived directly and independently from the visual features of a character. Similarly, Posner (1978) has claimed that, when a stimulus is presented, its identity, name and various aspects of meaning are automatically extracted, irrespective of the intentions of the subject. In this way, the category effect can easily be explained: since all items in a display are fully identified in parallel and since subjects know the category of the target letter, there is no need to perform any further operations on items already classified as non-targets. Since non-targets are rejected in parallel without spending any processing resources, there will be no effect of the number of non-targets for a between category search

(e.g., Duncan, 1983). According to this "late-selection" line of reasoning (Duncan, 1981; Hoffman, 1979; Schneider & Shiffrin, 1977) parallel pre-attentive processing across simultaneous stimuli is not limited to physical stimulus characteristics such as location, color (Broadbent, 1971), orientation and size (Treisman & Gelade, 1980), but form and meaning are also analyzed pre-attentively (e.g., Allport, 1977; Duncan, 1981).

Yet, one can also account for the category effect without the radical conjecture that all stimulus characteristics are encoded in parallel until reaching a semantic level. Instead only those features might be processed in parallel which are needed for categorizing a character as digit or letter. In a subsequent stage full identification might take place (Broadbent, 1982), which requires directing spatial attention to the location of the target (Hoffman, 1978). Jonides and Gleitman (1976) claimed that pre-attentive processing tags the categorically different item enabling a subsequent shift of focussed attention to the location of the tagged item for detailed processing. Phenomenally, the item that automatically attracts attention seems to "pop-out" from its background, (Hoffman, Nelson & Houck, 1983; Hoffman, 1986; Jonides & Gleitman, 1976; Neisser, Novick & Lazar, 1963; Treisman, 1988) similar to a red target popping out from blue non-targets (Kahneman & Treisman, 1984). The hypothesis that digits pop-out from letters and automatically attract attention has been confirmed by a study of Hoffman et al. (1983), in which it was shown that detection of a digit among letters was accompanied by an increase in the ability to perceive other shapes in the vicinity of the digit. A similar conjecture was made by Sagi and Julesz (1985a, 1985b) who claim that local detection of differences among features might proceed in parallel, while actual identifying targets requires focal attention. Hence, naming a target requires serial inspection by focal attention, whereas knowing a target's position is mediated by parallel processing (Sagi & Julesz, 1985a).

All these studies used a display in which a single categorically different target item could be present. In contrast, there appear limits in identifying several stimuli at once when multiple targets are presented simultaneously (e.g., Duncan, 1980). For example, in a study of Francolini and Egeth (1979), subjects searched for a specific digit among both digits and letters. Time to detect a digit not only increased with increasing numbers of within-category non-targets (digits), but also increased with the number of categorically different non-targets (letters), implying that subjects were unable to search selectively for digits. It was concluded that identifying categorically different items in parallel was not possible when more within-category items were presented simultaneously.

Both early and late-selection theories recognize the limit of perceiving simultaneous targets, yet they provide quite different explanations. According to the late-selection view, capacity limits only arise when simultaneous targets each are associated with distinct responses (Duncan, 1980, 1981, 1985). In such a view, selection takes place "late" in processing, primarily to select between different responses evoked by different stimuli (Allport, 1980; Keele & Neill, 1978). For example, in a study of Duncan (1980) accuracy for detecting a target at the 12 and 6 o'clock position in his display was much less when the other position also contained a target than when it contained a non-target. Accuracy of detecting a target is reduced when there are other targets in the display, whereas simultaneous non-targets do not have such an effect. However, it can be argued that the late-selection view predicts no capacity limitations when a single response reflects the combined outcome of simultaneous targets. Thus, in a "same-different" version of a target detection task, Donderi and Zelnicker (1969) found that the time to determine whether or not a varying number of geometric shapes (2-13) were all the same, was independent of the number of shapes presented. The number of targets did not have any effect because the "same-different" task required no separate response for each of the simultaneously presented targets.

According to the early-selection view, interference between two simultaneous targets does not arise from response selection or motor factors, but is due to a disruption of pre-attentive parallel perceptual processing. In this view, in case of a single categorically different item, attention is drawn to the location of the discrepant item. Because attention is captured automatically by the discrepant item, phenomenally, it seems that the item pops-out from its environment (Hoffman et al., 1983). However, when two or more categorically different items are present, these cannot "pop-out" simultaneously because attention cannot be divided between two or more locations at the same time (Posner, Snyder & Davidson, 1980). This might disrupt the efficiency of the parallel process, and search might proceed in a, at least partially, serial manner (e.g., Francolini & Egeth, 1979).

The present study is concerned with the extent to which two simultaneously presented targets can be identified in parallel, when these targets are categorically different from non-targets. Subjects searched for two target letters among a variable number of digits. Subjects responded "same" when the letters were identical and "different" otherwise. This "same-different" version of target detection ensures that the response is not merely based upon successful

discrimination of some target features (e.g., Folk & Egeth, 1989) but, instead, that targets have to be fully identified.

According to late-selection models all items in the display are identified in parallel, and targets pass into the limited capacity decision system (Duncan, 1983). Although it might be possible that simultaneous targets cause difficulty, the spatially parallel rejection of non-targets can assumed to be perfect (Duncan, 1985). As argued by Duncan (1980): "It is hard to detect simultaneous targets, yet the number of simultaneous non-targets is rather unimportant" (p. 284). Therefore, based on first level pre-attentive processing, only target letters will enter the second level of processing. Hence, the time to decide whether the two letters match will be independent of the number of digits in the display.

Alternatively, according to early-selection models, categorization may proceed in parallel but attention has to be shifted to the location of the item before an item can be identified. Since attention cannot be divided between two locations, the presence of more than one target interferes with the operation of the "pop-out" mechanism of categorically tagged targets. This might lead to a complete disruption of parallel pre-attentive processing, leading to a serial search through all locations that possibly contain the targets. Hence, the time to decide whether the two letters match will increase linearly with the number of non-targets.

2 METHOD

2.1 Task and Stimuli

Throughout a block of trials subjects fixated a dot (.3°) at the center of the stimulus field. In order to warn the subject, a high tone was presented 300 ms before stimulus presentation. The stimulus field remained on for 200 ms, which is sufficient to prevent effects of eye-movements. In a trial, two letters were presented together with a variable number of digits in a circular display with a 2° diameter. Each element was presented at one out of 8 possible positions which were equally spaced on the circumference and were .8° of angle apart. Both targets appeared equally often at each of the 8 possible locations for each condition. The remaining positions were randomly filled with either 2, 4 or 6 randomly chosen digits. On each trial, the two target letters were chosen among the items (D, K, P) which were the same target letters as used by Gleitman and Jonides (1978). In half of the trials the target letters were the same, in

the other half the target letters were different. Digits were chosen randomly from the set 2 through 8. Letters and digits were approximately .4° of angle in height.

2.2 Apparatus

The stimuli were presented on an Olivetti monochrome CRT, and a Olivetti M24 microcomputer controlled the stimulus presentations and collected responses. The computer program operated synchrone with the 60-Hz refresh of the CRT. The "shift" keys on the left and right side of the computer keyboard were used as response keys, and subjects pressed the appropriate key with the index finger of either the left or the right hand. The stimuli were presented in black against a green background with a luminance of approximately 2.1 cd/m^2 and 31.8 cd/m^2, respectively.

Subjects were individually tested in a sound-attenuated, dimly-lit room with their heads resting on a chin rest adjusted to a comfortable height. The CRT was located at eye level, approximately 60 cm from the point of viewing.

2.3 Subjects

Ten subjects, ranging in age from 17 to 24 years participated in the experiment. All had normal or corrected-to-normal vision and were right handed. They were paid for their participation.

2.4 Experimental design and procedure

The design of the experiment was a two factor within subject design (display size: 4, 6, 8 and response type: "same" and "different"), combinations of which were randomized within blocks. Following a practice session of 336 trials, each subject completed four experimental sessions, each consisting of three blocks of 112 trials. There were short rests between blocks of trials. An experimental session lasted approximately 25 minutes. Each subject had a total of 224 trials in each condition. Half of the subjects responded to "same" trials with the right index finger, and to "different" trials with the left index finger. This assignment was reversed for the other half of the subjects.

Two subjects were run in alternating sessions. The instruction was to indicate whether the two letters appearing in the visual field

were the same or were different by pressing one of two appropriately labeled buttons on the computer key-board with their index finger. Subjects were instructed to respond as fast as possible while minimizing errors. In case of an error, the computer beeped to inform the subject. If no response was made after 2000 ms, the trial was counted as an error.

3 RESULTS

Median RTs and error rates were computed for each subject in each condition. The data of one subject were eliminated in view of an error rate exceeding 20% in at least one experimental condition.

The average median reaction time (RT) and error rate over subjects for "same" and "different" responses at each level of display size is shown are Fig. 1.

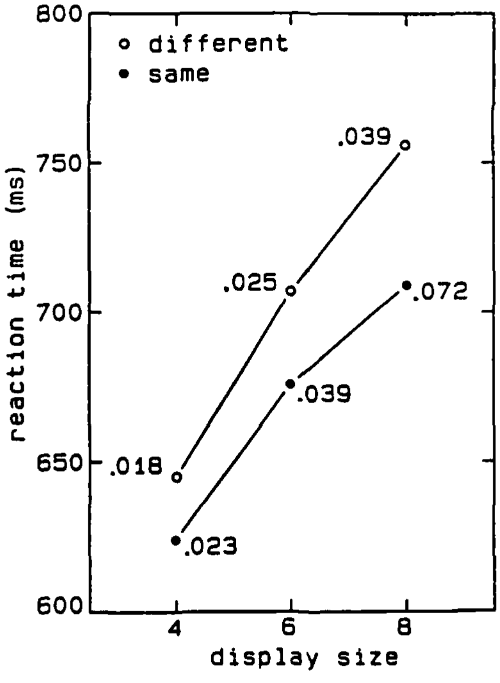

Fig. 1 Mean reaction time and error rates for "same" and "different" responses as a function of display size.

Median correct RTs for each subject were the cells of a within-subject ANOVA with response type (same vs different) and display size (4, 6, and 8) as main factors. The effect of response type

(same/different) was significant ($F(1,9)= 9.4$; $p < .05$). The overall effect of display size was significant ($F(2,18)= 105$; $p < .01$). Also, the interaction of response type with display size was significant ($F(2,18)= 8.8$; $p < .01$). The results show a clear display size effect suggesting that reaction time increases linearly with the number of non-targets.

In order to determine the slopes of the RT function, the individual median RTs were submitted to a linear regression analysis. The average slopes of the function of response type "different" and "same" were 29.2 and 22.3 ms, respectively. After reducing the subject error variance by using individual median RT of display size 4 as a baseline time, the differences in RT slopes showed the same pattern of results as the analysis of variance. There was a significant difference between the "different" and "same" slope functions ($t(50)= 2.32$; $p < .05$). In addition, both slopes were statistically different from a zero slope. For response type "different" ($t(25)= 13.45$; $p < .01$). For response type "same" ($t(25)= 12.71$; $p < .01$).

In order to achieve homogeneity of the error rate variance, the mean error rate per cell were transformed by means of an arcsine transformation. The transmitted data was entered into the same analysis of variance as performed on the response data. The results revealed a significant effect of display size ($F(2,18)= 25.2$; $p < .01$), response type ($F(1,9)= 10.0$; $p < .05$) and a significant interaction between display size and response type ($F(2,18)=6.9$; $p < .01$). The main effect of display size denotes that, as evident in the figure, error rates tended to mimic reaction time, suggesting that the increase of reaction time with display size cannot be attributed to a speed-accuracy trade-off.

4 DISCUSSION

The results show a clear display size effect for searching for categorically different targets among a variable number of non-targets. The failure to obtain selective search for letters among digits is demonstrated by the non-flat display-size functions. Unlike the relatively flat RT slope of 9.9 ms/comparison as reported by Gleitman and Jonides (1976), the RT slopes found in present study were 22.3 and 29.2 ms/comparison, respectively for "same" and "different" responses. The observation that categorically different non-targets interfere with two simultaneously presented targets suggests that one is not capable of fully rejecting all non-targets in parallel. This finding is inconsistent with the "late-selection" theory (Duncan,

1980, 1981). The usual late-selection account for capacity limits of perceiving simultaneous targets does not apply to the present study, since the separate targets did not each require a distinct response. In the present study, a response reflected the combined outcome of the simultaneous targets.

One still could defend the late-selection account by claiming that the detection of a target already involves a decision. In such a view, "target detection decisions" are more important than distinct responses to either target. Although theoretically viable, such an argument weakens the late-selection account since, similar to an "early" selection conception, it assumes a perceptual role for attention. And even in view of this argument, it cannot explain the present findings since this version of late-selection theory would still not have predicted interference from simultaneous non-targets.

In conclusion, the category effect, often cited as evidence in support of late-selection theory, diminishes as soon as two targets are presented simultaneously. Since the present study used a "same-different" version of target detection, this interference cannot be attributed to different responses arising from the multiple targets. Therefore, in line with the early-selection view, the locus of interference of simultaneous targets is perceptual, and not decisional as contended by late-selection theory.

Of additional interest of the present data is the finding that the RT for responding "same" and "different" shows the typical "fast-same" effect, a phenomenon which is the basis for long contentious debates among "same-different" judgment theories (e.g., Farell, 1985). Two different theories are widely accepted. First, Krueger (1978) has proposed a "noisy operator" hypothesis that assumes that the "fast-same" effect is due to rechecking that is performed for "different" judgments. The reason why rechecking is necessary for "different" judgements is that internal noise is more likely to result in spurious mismatches of features than in spurious matches. Second, Proctor's (1981) hypothesis attributes the "fast-same" effect to inhibition arising from competing identification codes. Identical stimuli activate only one naming response, whereas different stimuli activate two. The two activated name codes mutually inhibit each other, resulting in slower responding.

Both versions of "same-different" judgment theories seem to relate to the "early-late" selection issues discussed above. The "fast-same" effect according to Krueger (1978) seems to relate to the early-selection account of limits of perceiving simultaneous targets since both views attribute these effects to perceptual interference. Alternatively, Procter's (1981) account of the "fast-same" effect relates to late-selection theory because both views assume interfer-

ence at response selection. Neither theory, however, can account for the "fast-same" effect as observed in the present study, since both models predict a reduction of the "fast-same" effect with increasing display size. In line with Krueger's theory, one expects that internal noise increases with display size, leading to an increase in the number of "same" trials for which a recheck is necessary. The data, however, show relatively faster "same" responding with increasing display size. Yet, in line with Krueger's account is the finding that responding "same" is relatively fast and error prone, whereas responding "different" is slower and more accurate. According to Proctor (1981), introducing more noise is thought to increase the number of mismatching features leading to an increased response priming of "different" responses relatively to "same" responses. Therefore, this theory would also predict slowed "same" and speeded "different" judgments. It should be realized, however, that the observed "fast-same" effect increase with display size can be due to trading accuracy for speed. Clearly, the difference in responding "same" and "different" is important in distinguishing competing models of "same-different" judgment theories. However, it is not of primary concern of the present study, and does not particularly bear on the conclusions reached above.

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Several studies have shown that the time to detect whether a single target categorically different from non-targets is present or not, is relatively independent of the number of non-targets in the display. Invariance of performance with display size is taken as evidence in favor of late-selection theories claiming unlimited-capacity, spatially parallel processing of all items in the display. As an extension of previous studies, in the present study two categorically different targets were presented simultaneously among a variable number of non-target. Subjects were shown brief displays of two target letters among either 2, 4 or 6 non-target digits. Subjects responded "same" when the two letters were identical and "different" otherwise. Since the "same-different" response reflects the combined outcome of the simultaneous targets, late-selection theory predicts that the time to match the target letters is independent of the number of non-target digits. Alternatively, early-selection theory predicts a linear increase of reaction time with display size since the presence of more than one target disrupts parallel pre-attentive processing, leading to a serial search through all items in the display. The results provide evidence for the early-selection view since reaction time increased linearly with the number of categorically different non-targets.

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